TWI Ltd
Granta Park
Great Abington
Cambridge CB21 6AL
United Kingdom

Tel: +44 (0)1223 899000
Fax: +44 (0)1223 892588
E-mail: twi@twi-global.com
Web: www.twi-global.com

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Andy Norman
European Space Agency M&P Division
Postbus 299
Keplerlaan 1
Noordwijk 2200 AG
The Netherlands

Dear Andy,

TWI Report: Electron Beam Welding for Safety Critical Space Applications: Executive Summary Report
Report No: 25000/048v1/18

Please find below the TWI Report 25000/048v1/18, 'Electron Beam Welding for Safety Critical Space Applications: Executive Summary Report'. If you have any questions regarding the report please contact me.

Yours sincerely

Tim Mitchell
Principal Project Leader
Electron Beam Section
Joining Technologies Group
e-mail: tim.mitchell@twi.co.uk

Mike Nunn
Section Manager
Electron Beam Section
Joining Technologies Group
e-mail: mike.nunn@twi.co.uk

cc: Commercial Group, Master Files - TWI

Electron Beam Welding for Safety Critical Space Applications: Executive Summary Report
TWI Report 25000/048v1/18

Executive Summary

Background

The European Space Agency (ESA) awarded TWI Ltd (TWI) a programme of work based on the document RFQ/3-14222/14/NL/PA. This document detailed a scope-of-work (SoW) to be performed for the review of electron beam (EB) and laser beam welding processes for safety critical space applications with the focus of the project targeting stainless steel flow control valves (FCV). The programme covered material procurement, typical materials, joint configurations and weld development. The final part of the programme was to produce a series of demonstration components for mechanical testing. Airbus Defence and Space (ADS) were involved in the programme, providing vital input as to the design and manufacture of current production FCVs.

Objectives

The overall objective of this project was to review electron beam and laser welding processes such that a comparison could be made between the processes to assure that a welding technology exists with a technology readiness level (TRL) that is demonstrably at TRL7-9. The project targeted stainless steel FCVs, however it is expected that the results and conclusions can be read across to other safety critical space applications.

Scope

This document is the final summary report for the complete scope of work and summarises the results of the study. It also includes a critical analysis of the study and provides recommendations for applications in typical valve designs.

The original scope of work (SoW) had eight areas of interest, which required investigating during the project, these were:

- Typical materials, dimensions, locations and weld joint types used in the current design of FCVs manufactured in Europe.
- Design of a simplified valve demonstrator (leak tight container) which would demonstrate the applicability of the welding processes to FCVs.
- Development of process conditions for laser beam welding and EB welding such that high quality welds could be reliably produced.
- Manufacturing of representative welds on flat coupons using both laser beam welding and EB welding.
- Investigation of state-of-the-art non-destructive inspection (NDI) techniques in order to identify and characterise the types of critical defects found in welds made by the two processes.
- Manufacturing and characterisation of circumferential welded specimens, to ensure that processing conditions optimised for flat plates could be successfully translated to curved surfaces.
- Manufacturing of several demonstrator valves and subsequent vibration and mechanical testing.
- Assessment of the performance of each of the welded joints to determine which process was best for each weld location.

Work Structure

To address the project objectives and the SoW requirements the project was divided into six tasks/work packages, these were:

- Work package 1: Project management. This specified the requirements for the project documentation such as the product assurance and quality plans and the procurement of materials and traceability.

- Work package 2: Flow control valve description. Required TWI to perform a target application survey. The survey identified the typical materials, weld locations and dimensions used in the manufacturing of FCVs.

- Work package 3: Baseline material characterisation. Outlined testing to establish the baseline performance of the material in the un-welded condition.

- Work package 4: Optimisation of the welding process parameters. Developed the welding parameters for the two welding processes, laser beam welding and electron beam welding, with the primary goal of showing best practice and resulting quality for the target materials and penetrations outlined in work package 2.

- Work package 5: Property evaluation of optimised welding processes. Detailed the initial testing (metallographic, tensile and NDI) of welded flat plate coupons and the more detailed testing following down-selection (fracture toughness, fatigue crack growth rate and stress corrosion cracking).

- Work package 6: Manufacturing and testing of the demonstrators. Required TWI to design and manufacture 10 demonstrator FCV components and perform non-destructive and destructive evaluations of the components.

Conclusions

The overall objective was to review EB and laser welding processes such that a comparison could be made between them to assure that a welding technology exists that is demonstrably at TRL7-9. Considering all the results that have been obtained during this work programme the main conclusions are:

1. Both the EB and laser processes are at TRL 7-9 for flat plate and FCV demonstrator type component geometries in stainless steels.
2. Down-selection between the EB and laser processes is difficult based on mechanical testing alone; microstructural and processing differences should also be considered for the particular material to be joined.
3. Avoidance of lack of root and/or side wall fusion is better assured when using EB, rather than laser, as the welds can be made slightly wider, and process power changes and part manipulation can be more readily controlled using standard format equipment; whereas the format of laser equipment can vary significantly, giving variability in results.
4. Care needs to be taken when developing dissimilar metal welding procedures.
5. Low heat inputs are required for materials which are susceptible to weld sensitisation.

Recommendations for Applications in Valves

Where partial penetration welds are designed into the component care needs to be taken to ensure porosity levels are controlled. In general EB welds should produce less porosity in most cases for this type of weld, depending on the penetration depth required and the material being welded.

The material selection needs to be considered as some materials, eg titanium, are more difficult for conventional laser processing to meet porosity quality requirements, particularly when making partial penetration welds. In these cases the simplest option would be to use EB welding. The comparable quality of laser welds made in stainless steel in this work have been achieved by swapping to nitrogen gas shielding, that gas being soluble in the welds as they freeze.

Dissimilar metal welds in stainless steel alloys also need to be developed with care as some welding conditions can cause weld sensitisation in susceptible alloys. In these cases it is prudent to keep heat-inputs as low as practical to avoid unfavourable weld/heat affected zone (HAZ) microstructures. In this respect, both processes can be suitable.

During qualification programmes where mechanical testing is required, test specimen production and preparation approaches should be verified in advance if the welds are of a small size, ie 3mm penetration depth or less.

With careful control of key parameters and sufficient process development there should be no difference in the quality of welds produced by either the EB or laser processes, bearing in mind the caveats regarding partial penetration welds and materials selection made above.

In thin section, tight fitting, joints it is challenging to align the welding beam to find and track the joint. The EB welding process has proven to be more accommodating in this regard as small beam manipulations (effectively increasing the weld width and tolerance to joint tracking) can be more readily achieved than when using a laser, where missed joints or partial lack of fusion are more possible. There is a balance to be struck in terms of weld width, to assure the joint is fully fused and that the heat input is not excessive. For both processes the ability to view coaxial with the welding beam during setup is greatly beneficial in this scenario.

Implementation of beam quality measurements using the BeamAssure™ system for EB and other commercial systems for laser systems is recommended. The systems are capable of highlighting variations in beam parameters which could otherwise lead to inconsistent welding results and the scrapping of high value components. System performance can also be tracked and linked to maintenance events, potentially reducing system down times.

